Resonance Spin Structure

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Jefferson Lab RSS Collaboration

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Analysis: Paul Mckee, Karl Slifer, S. Tajima, Frank Wesselmann, Hongguo Zhu, (Peter Bosted, Eric Christy)

Hall C January Meeting on Jan.25, 2007

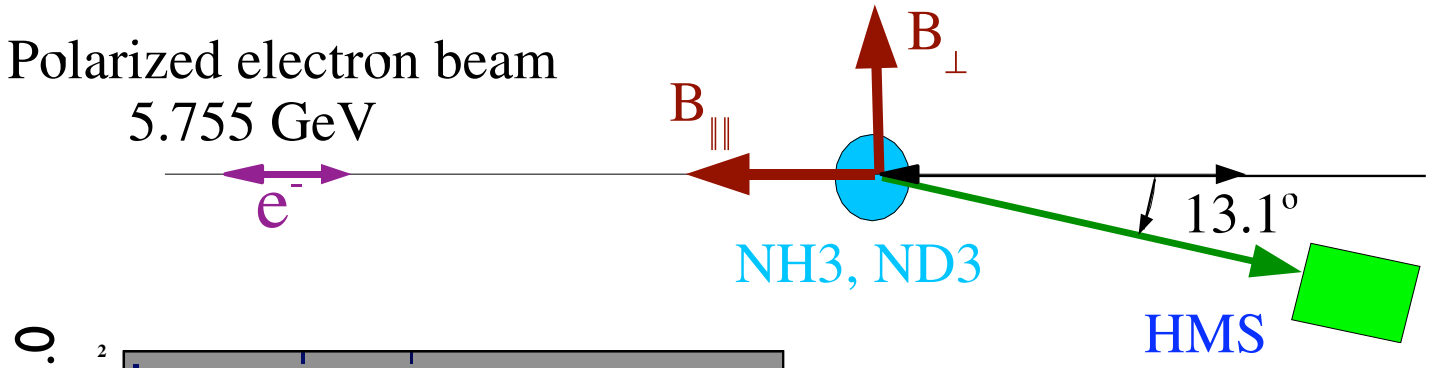
The physics goals

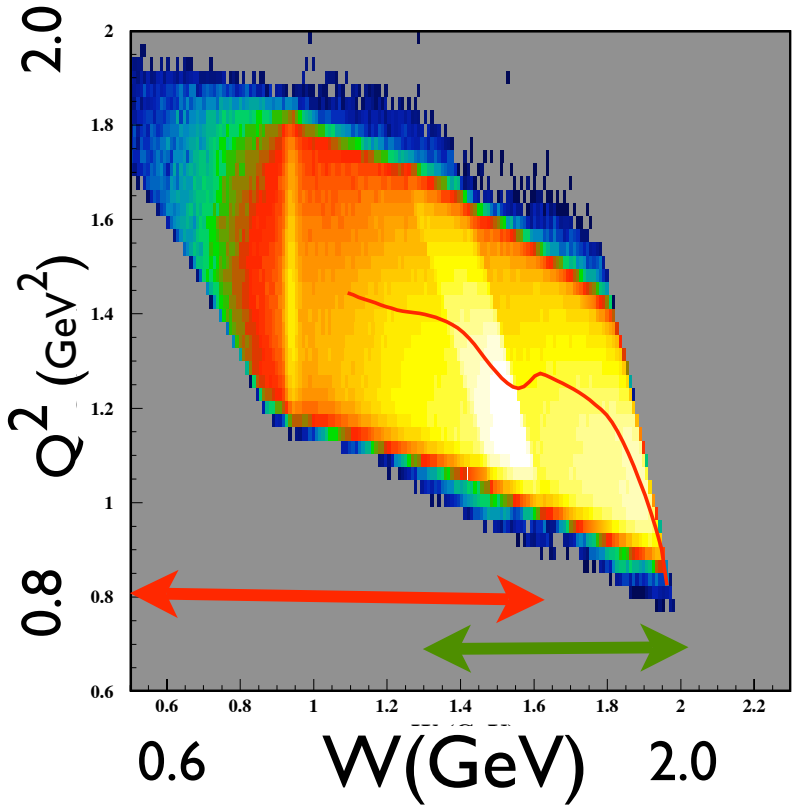
- Measure proton and deuteron spin asymmetries $A_1(W, Q^2)$ and $A_2(W, Q^2)$ in the nucleon resonance region ($1.1<W<1.9$ GeV) at four-momentum transfer squared $Q^2 \sim 1.3$ $(\mathrm{GeV}/c)^2$. => Study W dependence.

- Extract polarized structure functions g_1 and g_2 and study:
  i. Polarized local duality
  ii. Twist-3 effects from moments of g_1 and g_2

- Extract Neutron spin structure functions from the proton and deuteron data.
- Calculate GDH Sum rules, Quark polarizations

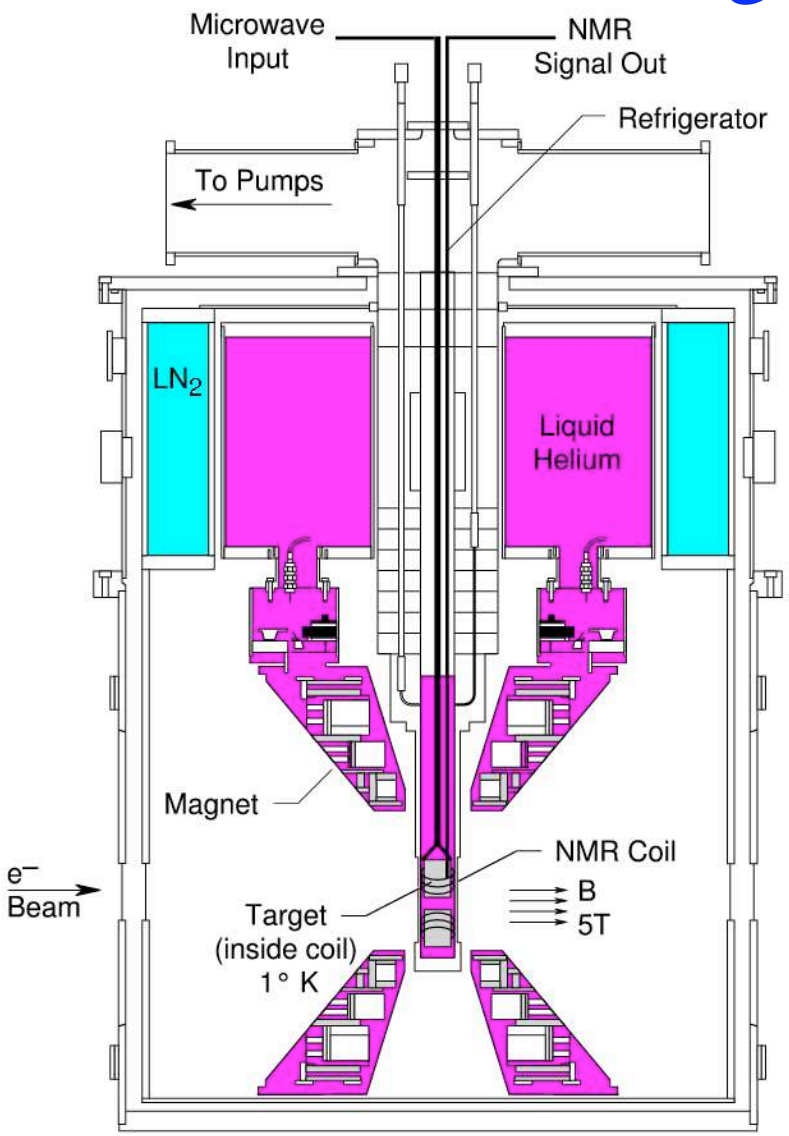
RSS Experiment in Hall C at JLab





- High Momentum Spectrometer (HMS) detects scattered electrons. Momentum settings: 4.7 , 4.1 GeV/c
- $\langle Q^2 \rangle$ =1.3 GeV^2 , 0.8<W<2.0 GeV. W: Elastic+Resonance regions.
- I ~ 100nA for NH_3 and ND_3
- Beam Polarization (P_B) by Moller:
  P_B = 65.5 ± 2.6 (%) for $B_{||}$
  P_B = 70.9 ± 1.7 (%) for $B_\perp$
- Beam charge asym. < 0.1%

Polarized Targets ($^{15}NH_3$ and $^{15}ND_3$)



- Dynamic Nuclear polarization driven by microwave
- ^{4}He evaporation refrigerator
- 5T polarizing field on target.
- NMR system for polarization measurement
- Polarization can be flipped by 180°. Ran ± for equal times
- Average target polarization
  P_T =68 % (NH_3); 18 % (ND_3)
- Relative systematic error ~2.9%

Proton Elastic Asymmetry

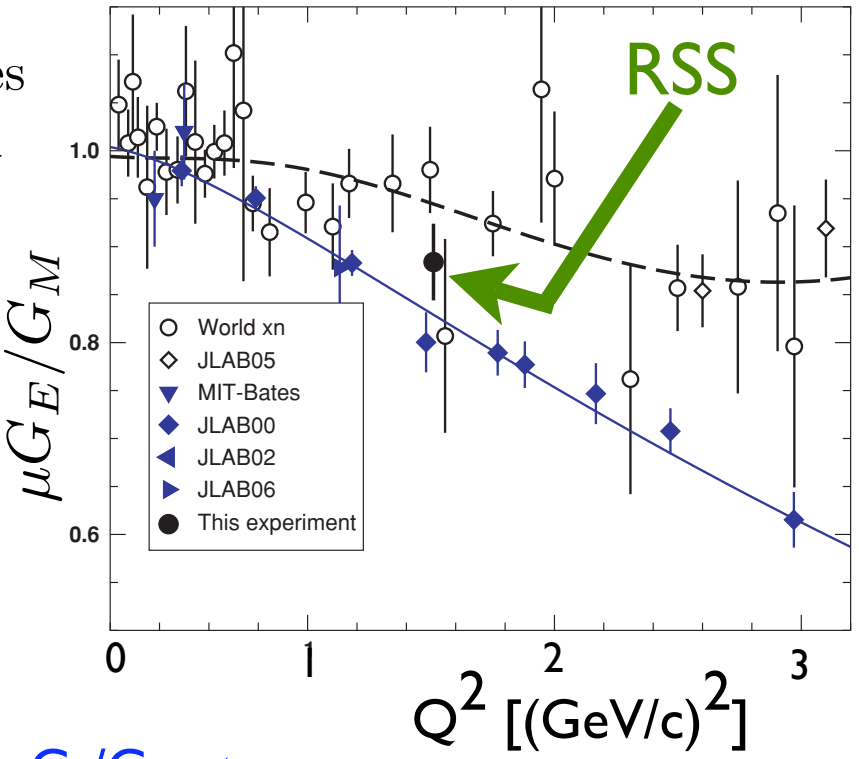
$$A_{el} = \frac{K_1 \cos\theta^\star + K_2 \frac{G_E}{G_M} \sin\theta^\star \cos\phi^\star}{G_E^2/G_M^2 + \tau/\epsilon}$$

$\theta^\star, \phi^\star$ = polar and azimuthal angles between $\vec{q}$ and target spin

K_1, K_2 = kinematic factors

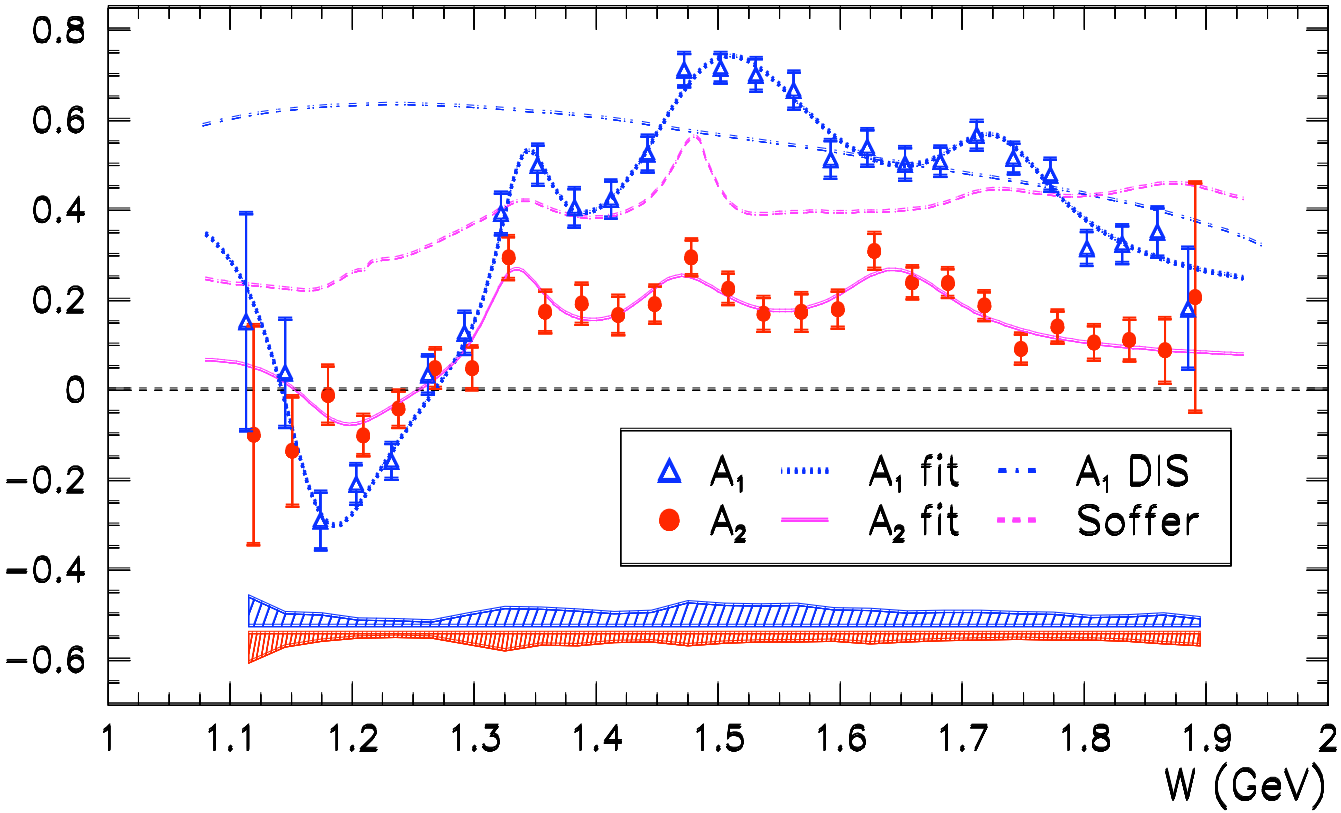
Sensitivity	$\parallel$	$\perp$
$\frac{\Delta A_{el}/A_{el}}{\Delta \frac{G_E}{G_M} / \frac{G_E}{G_M}}$	0.02	~1.0

M.K. Jones et al
Phys. Rev. C 74, 035201 (2006)



- The product $P_B \cdot P_T$ extracted from $A_{\parallel}$
- Ratio of the Proton EM Form Factors, G_E/G_M at Q^2=1.5(GeV/c)^2, measured from $A_\perp$ (results published)

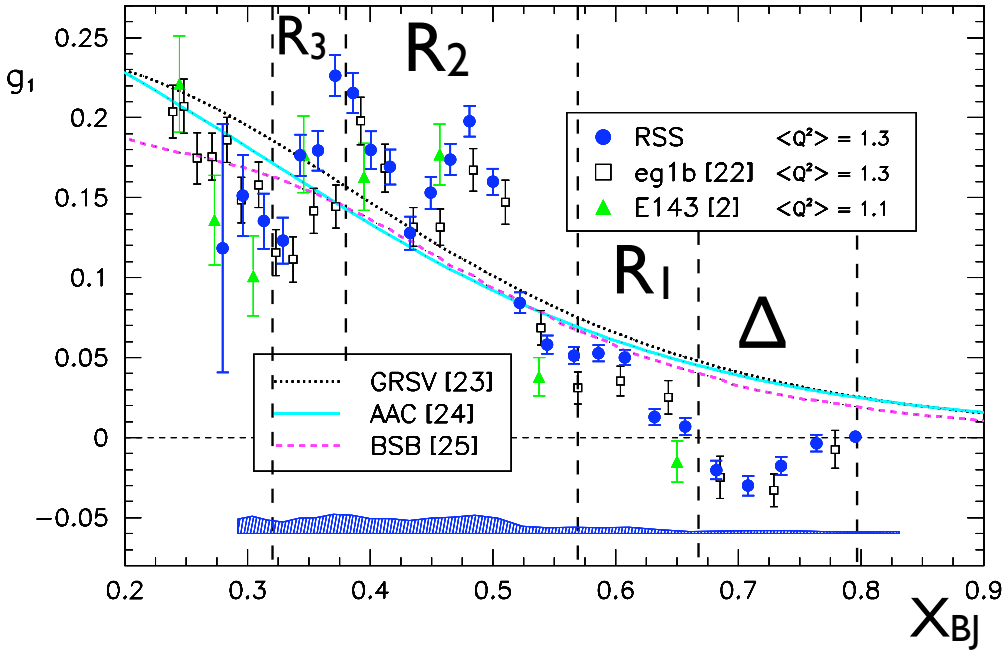
Proton A_1 and A_2 versus W



- A_1 and A_2 are extracted from $A_{||}$ and $A_{\perp}$ using Hall C R fit by M.E. Christy

Proton g_1 and Study of Polarized Duality

g_1 versus $X_{BJ}=Q^2/2M_p(E-E')$



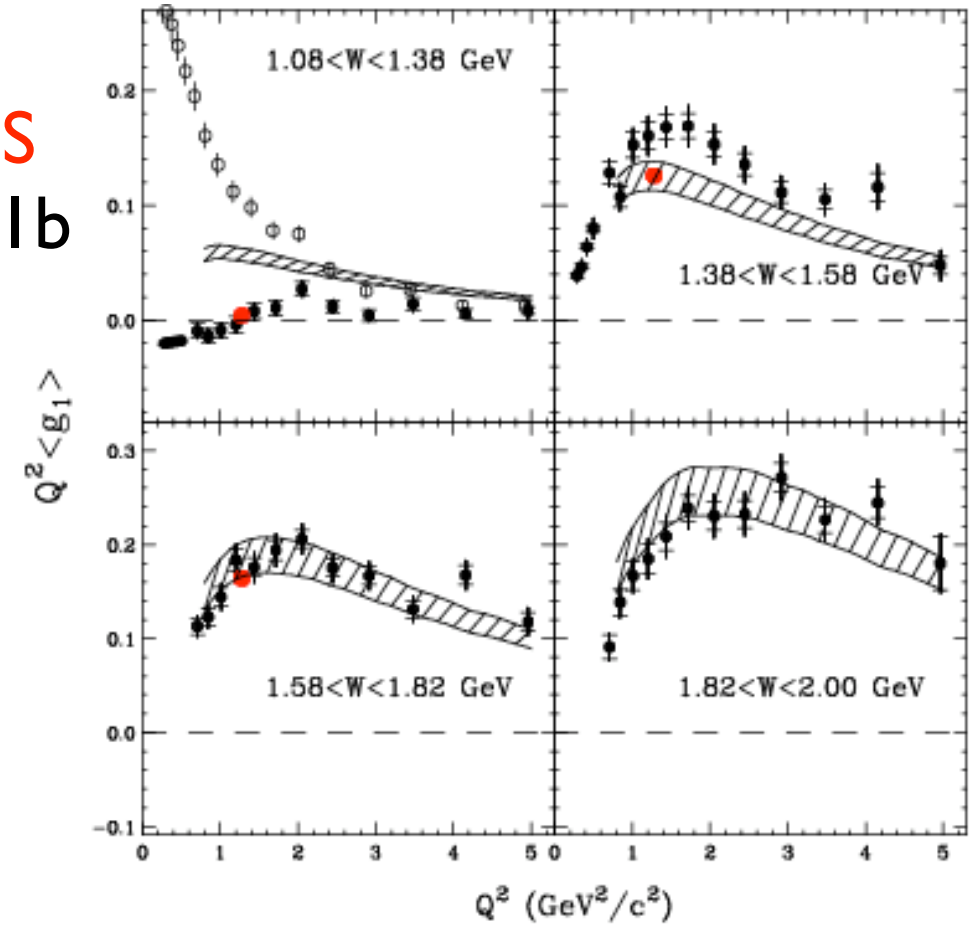
NLO PDFs (BSB, GRSV, AAC) have been evolved to $Q^2=1.3$ GeV^2, and have target mass corrections.

	W range	Ratio of Integrals (PDF and data fit)
Delta	1.11--1.30	3.93 ± 0.56
R1	1.30--1.39	1.38 ± 0.10
R2	1.39--1.68	0.78 ± 0.05
R3	1.68--1.79	0.81 ± 0.06
Global	1.09--1.91	1.17 ± 0.08
M−R1	0.94--1.40	0.42 ± 0.06
R2 +	1.40--1.91	0.87 ± 0.06

- Quoted errors are for the data only. Phenomenology systematics for the PDFs (±0.06 for the global ratio) needs to be added.
- Local duality is not observed in proton g_1 at $Q^2=1.3$ GeV^2
- The global ratio becomes worse (1.42 ±0.10) if large-x resummations for the PDFs (Bianchi et al, PRD 69, 014505 (2004)) are included.

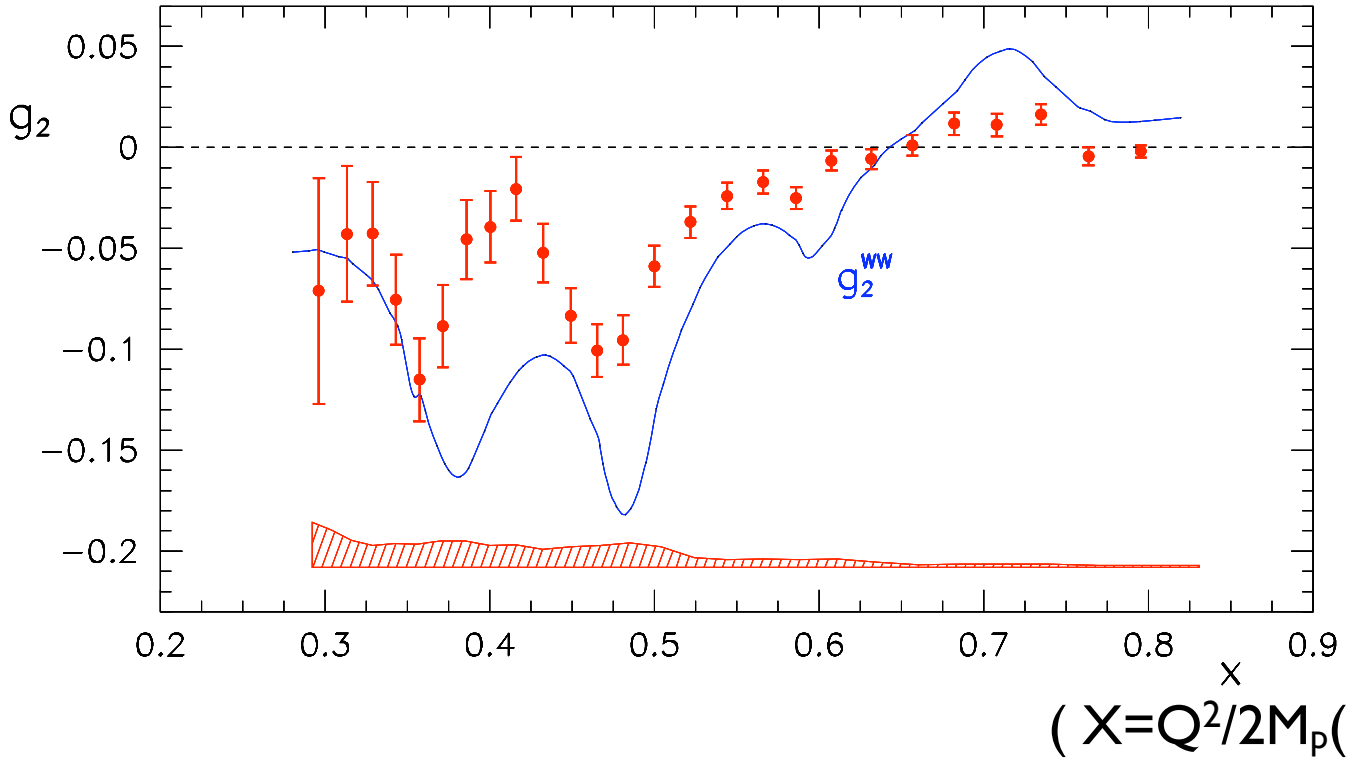
Comparison of RSS proton g_1 to eg1b results

- RSS
- eg1b



- Q^2 dependence of Q^2 <g1> for each W region indicated is shown above. (Taken from Fig.3 of hep-ph/0607283 (P. Bosted et al) and RSS data added)
- Hatched bands show the average ranges calculated from extrapolated NLO DIS fits

Proton g_2 and Higher Twist



($X=Q^2/2M_p(E-E')$)

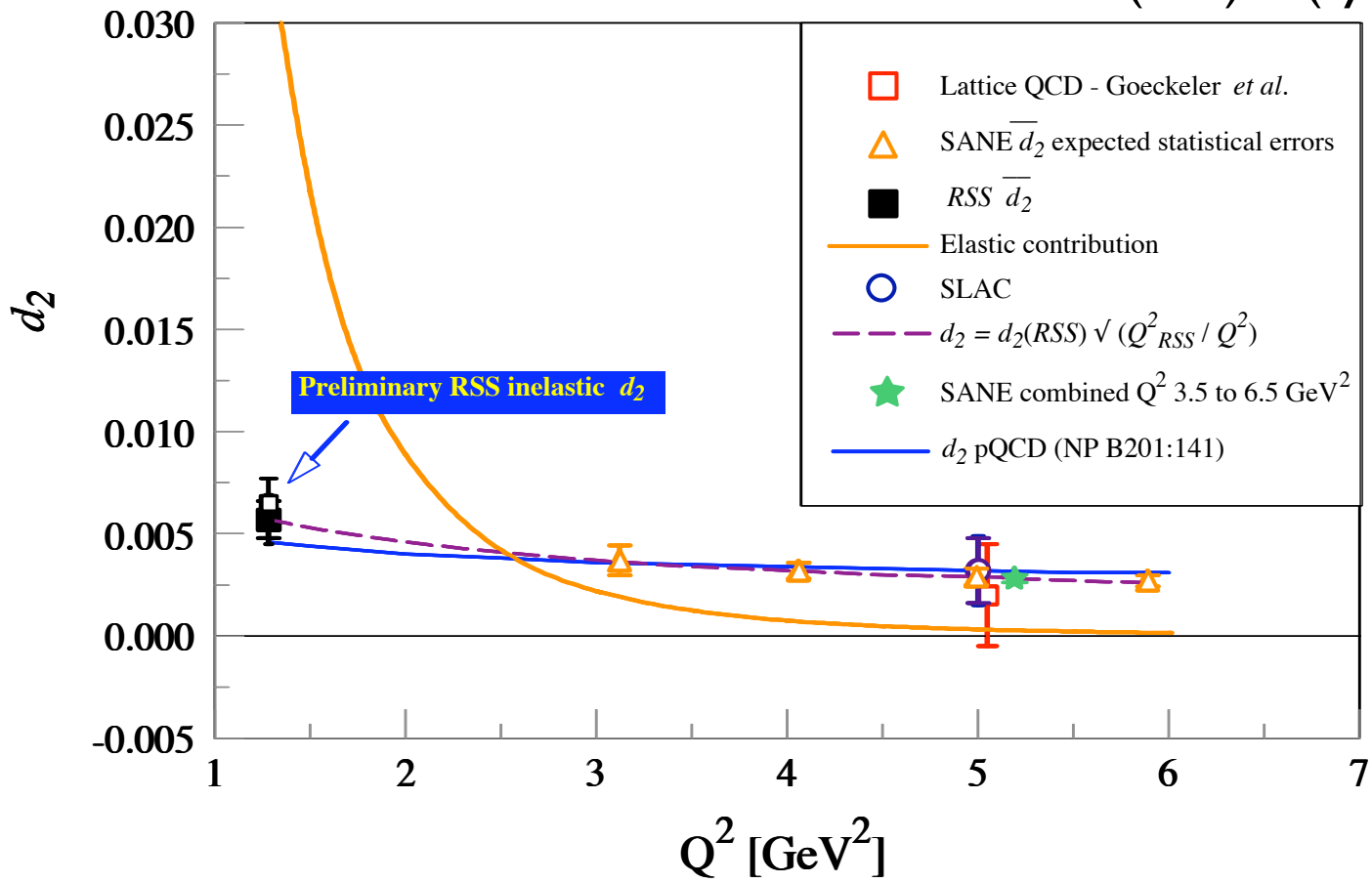
$$g_2 = g_2^{WW} + \bar{g}_2; \quad \text{Twist 2} : g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 \frac{dy}{y} g_1(y,Q^2)$$

- Use measured g_1 to calculate g_2^{WW}

Twist-3 Matrix Element d_2

$$d_2 = \int_0^1 x^2(2g_1 + 3g_2)dx = 3\int_0^1 x^2(g_2 - g_2^{WW})dx$$

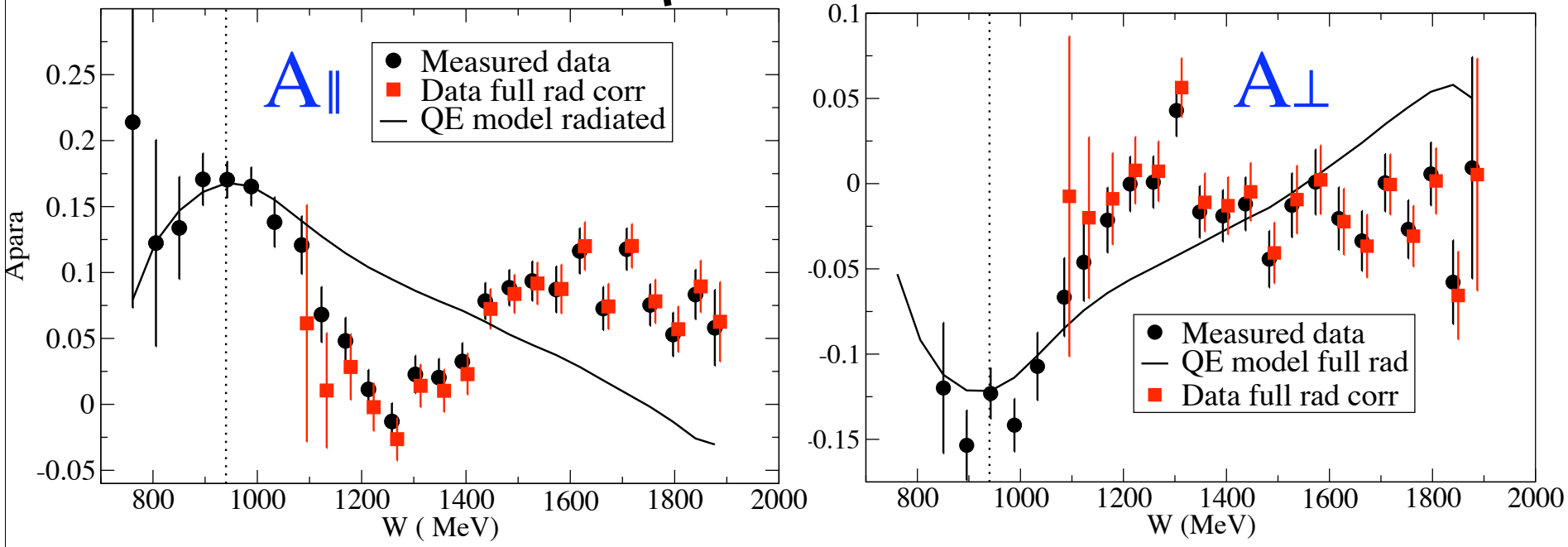
$$\text{[RSS]}\ \overline{d_2} = \int_{0.29}^{0.84} x^2(2g_1 + 3g_2)dx = 0.0057 \pm 0.0009\ (\text{stat}) \pm 0.0007\ (\text{syst})$$



- The measured $\bar{d}_2$ (RSS) is more than 5 sigmas above zero
- pQCD evolution courtesy of A. Deur

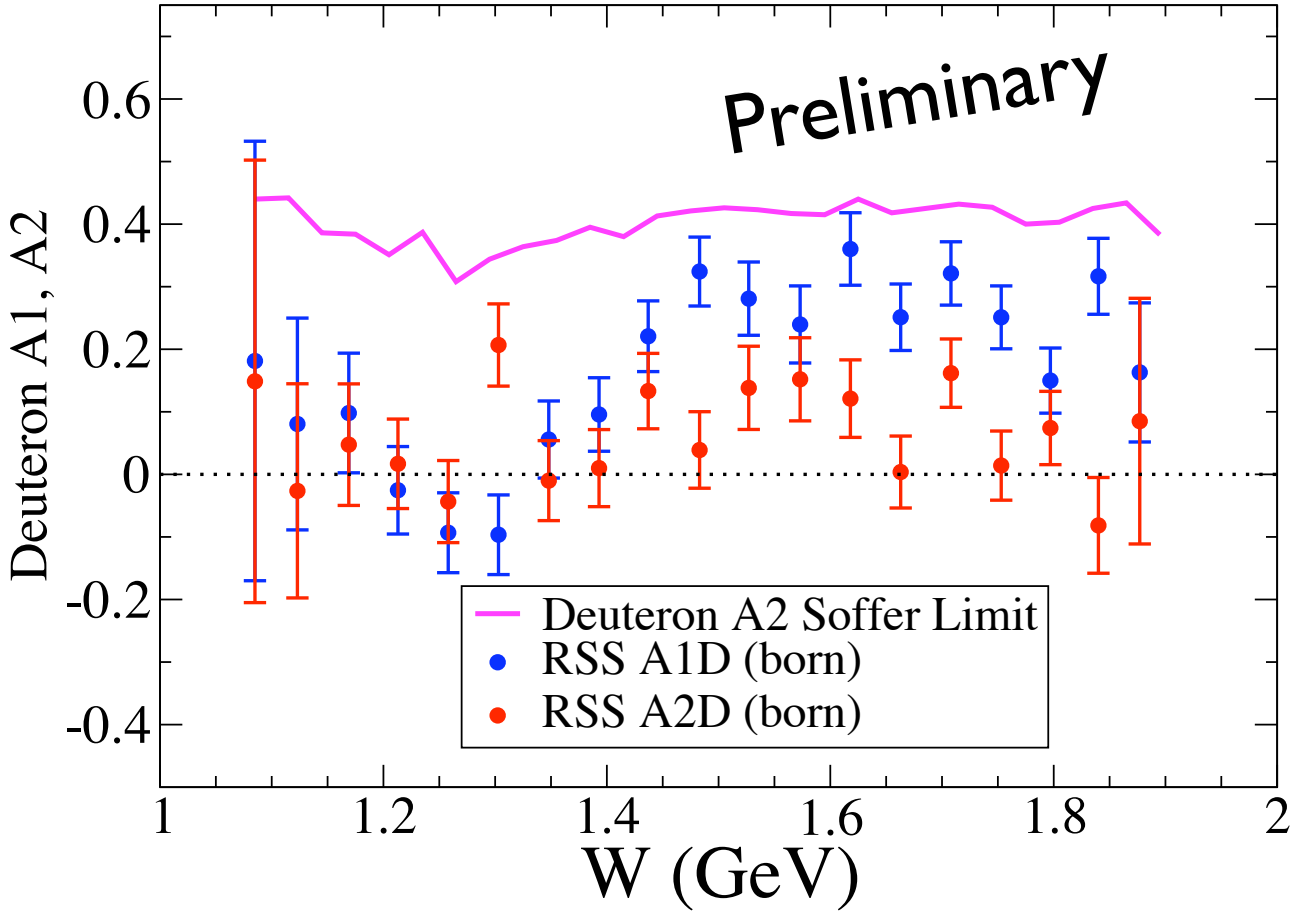
Deuteron A∥ and A⊥ versus W

Preliminary



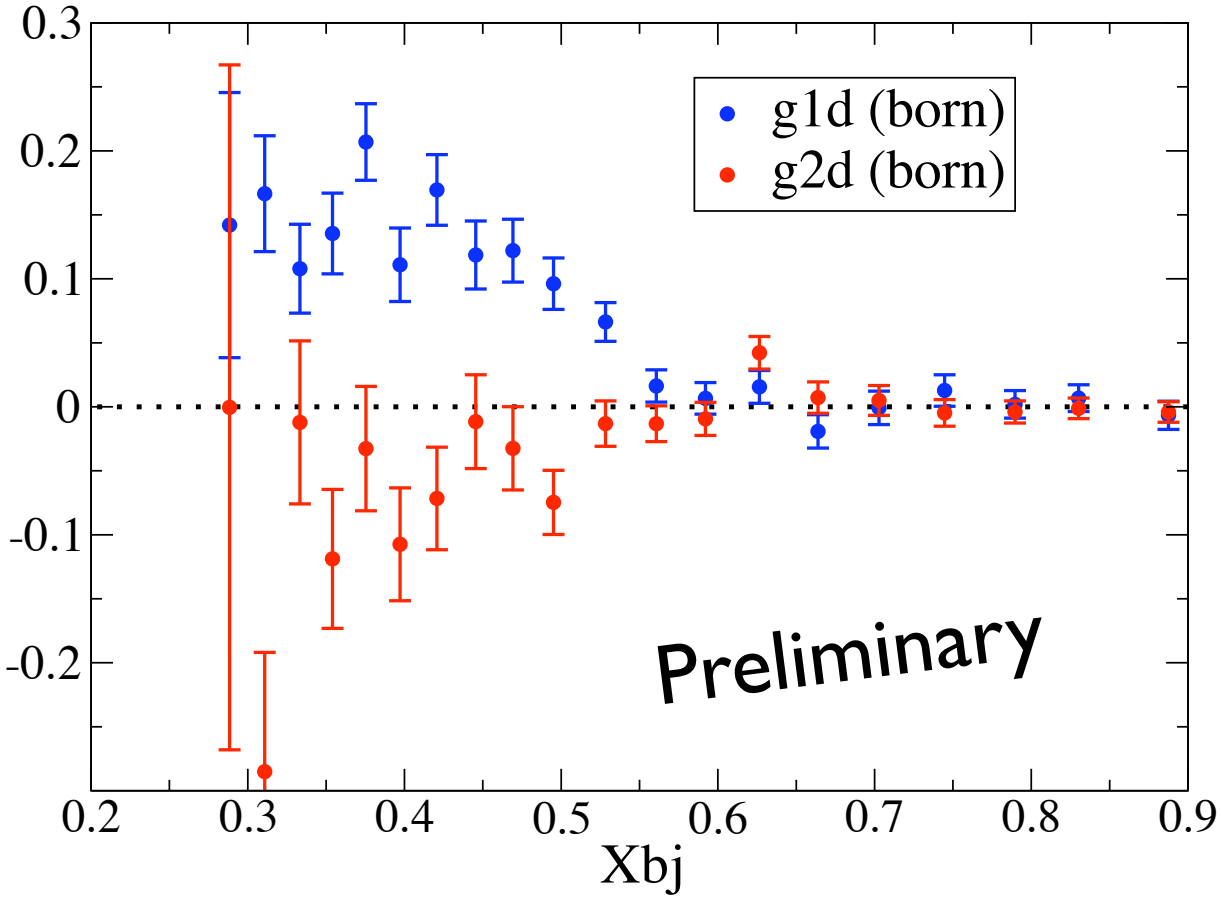
- Arenhövel calculated the deuteron QE cross sections, A∥ and A⊥ at RSS kinematics. Dipole form factor with Gen=0 was used.
- Arenhövel's QE asym models agree with data in the QE region
- Radiative corrections have been applied to our data.

Deuteron A_1 and A_2 versus W



- Radiative corrections have been applied.

Deuteron g_1 and g_2 versus x



- Radiative corrections have been applied.
- P. Bosted's deuteron fits were used to obtain F_{1d} , F_{2d}

Extraction of Neutron Spin Structure

- Extraction of neutron spin structure functions (SSFs) from the RSS proton and deuteron data
- Smeared proton SSFs need to be subtracted from the deuteron SSFs.
- We employ Bodek-Ritchie version of Atwood-West smearing technique: Form the convolution of the momentum distribution and on-shell quantities

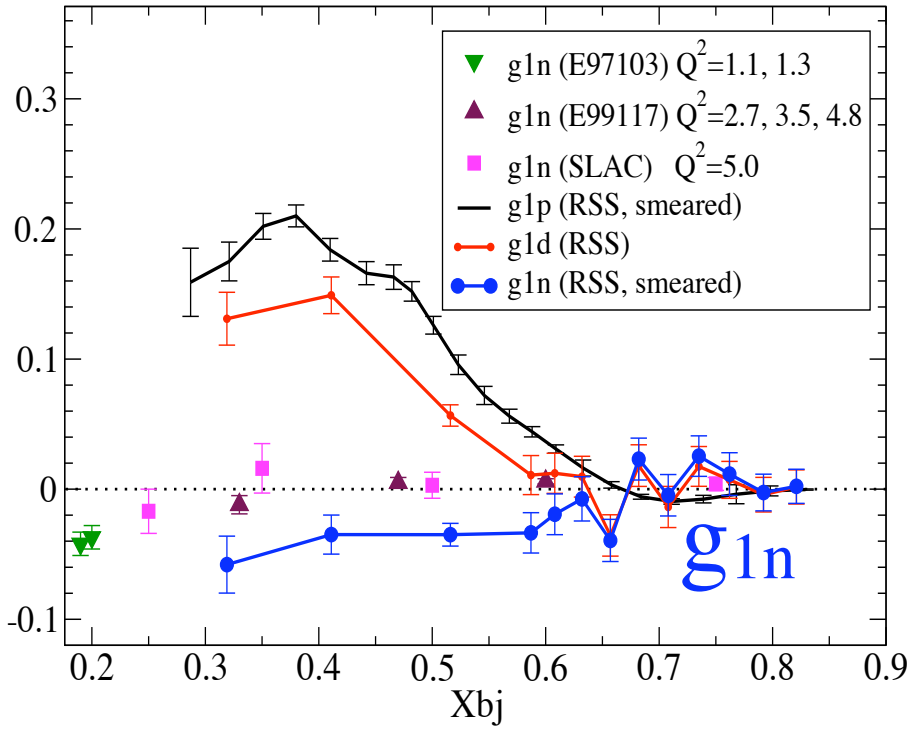
$$F(Q^2,\nu) = \int_0^\infty \mid f(\vec{p}) \mid^2 g(Q^2, W', \nu') d\vec{p}$$

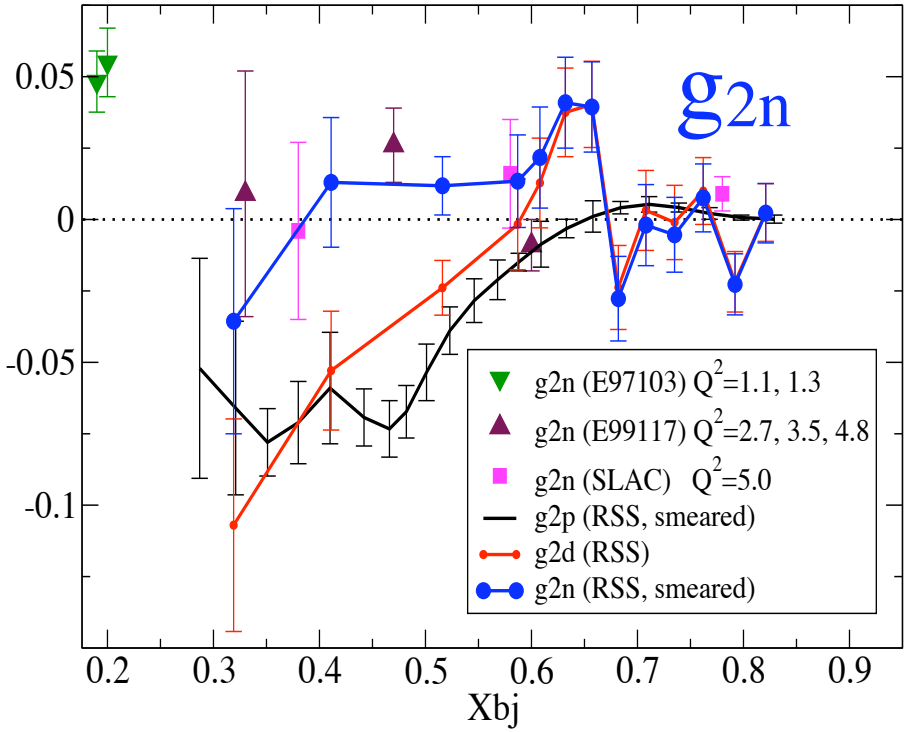
- Need to obtain smeared proton g_1 and g_2

$$\begin{matrix} g_1^p \\ g_2^p \end{matrix} \rightarrow \begin{matrix} \Delta\sigma_{\parallel}^p(g_1^p, g_2^p) \\ \Delta\sigma_{\perp}^p(g_1^p, g_2^p) \end{matrix} \xrightarrow{\text{Smear}} \begin{matrix} \Delta\sigma_{\parallel}^{ps} \\ \Delta\sigma_{\perp}^{ps} \end{matrix} \rightarrow \begin{matrix} g_1^{ps} \\ g_2^{ps} \end{matrix} \rightarrow \begin{matrix} g_1^{ns} = g_1^d - g_1^{ps} \\ g_2^{ns} = g_2^d - g_2^{ps} \end{matrix}$$

Smeared Neutron g_1 and g_2 versus x

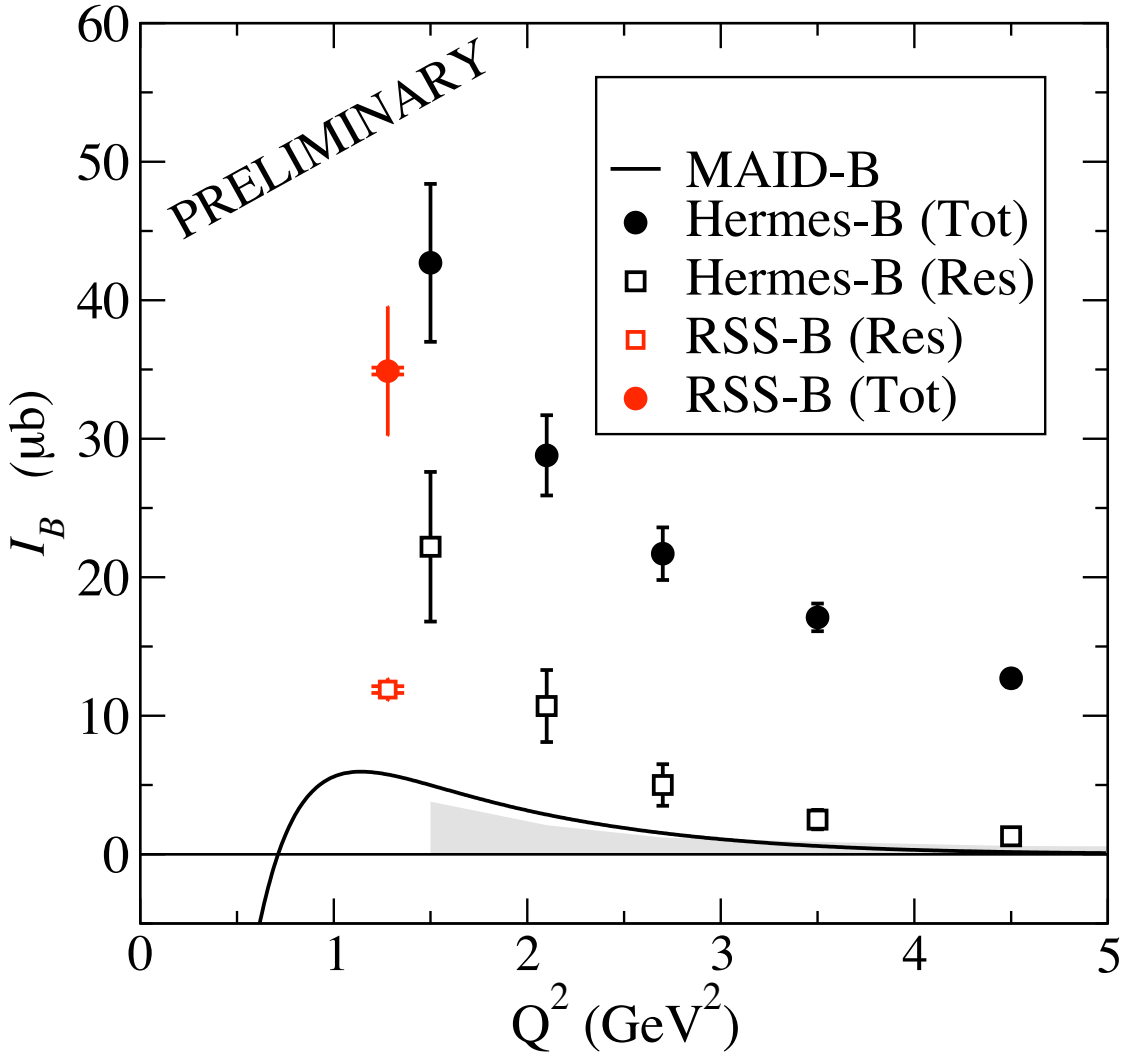
RSS: Preliminary





- Radiative corrections applied to RSS data.
- Previous measurements (JLab E97-103, E99-117, SLAC) were in the Deep Inelastic Scattering (DIS) region

GDH Sum rule from RSS proton data



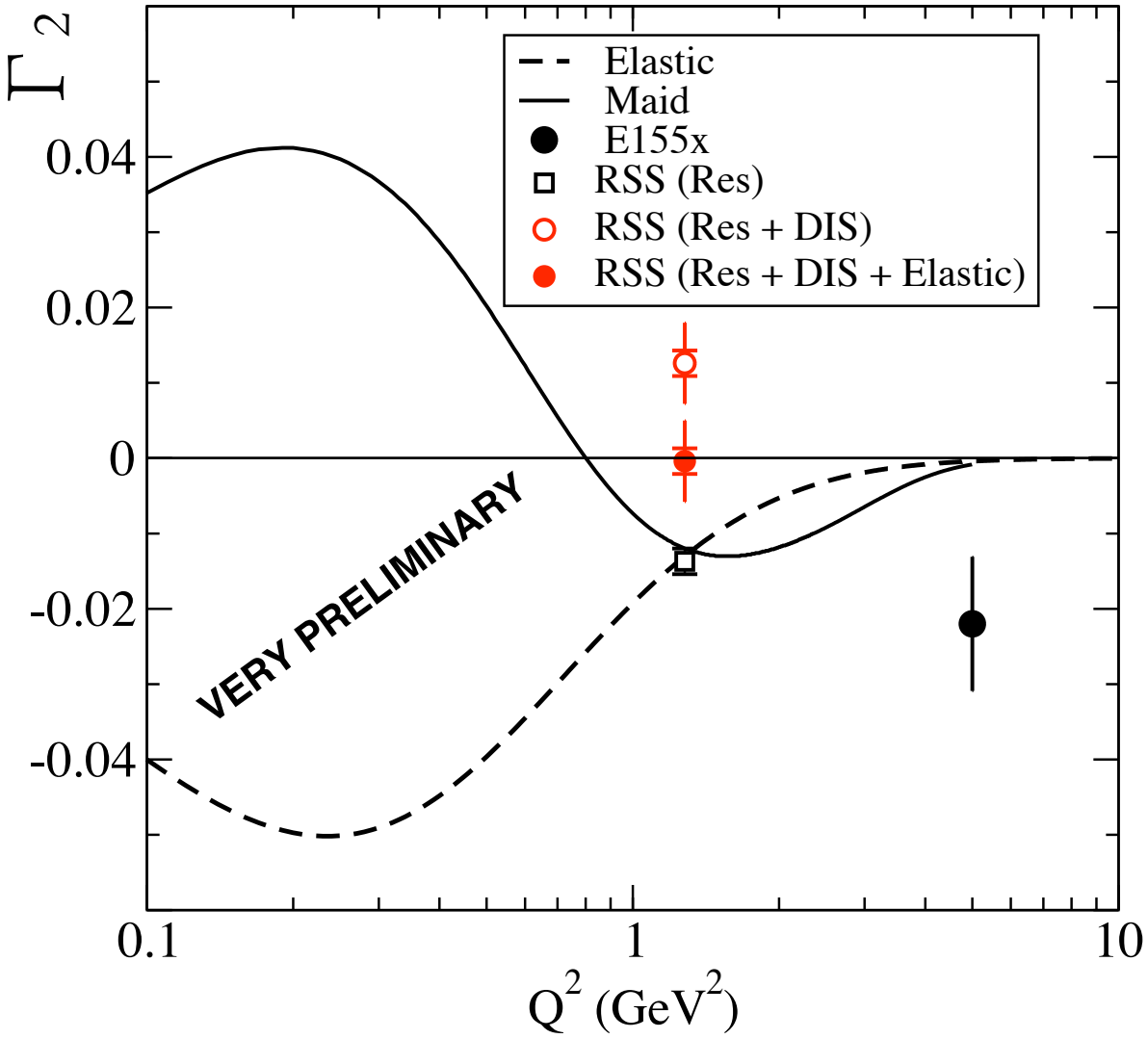
$$I_B = \tilde{I} \int_0^{x_{th}} \frac{g_1(x) - \gamma^2 g_2(x)}{\sqrt{1+\gamma^2}} dx$$

where

$$\tilde{I} = \frac{16\pi^2\alpha}{Q^2}$$

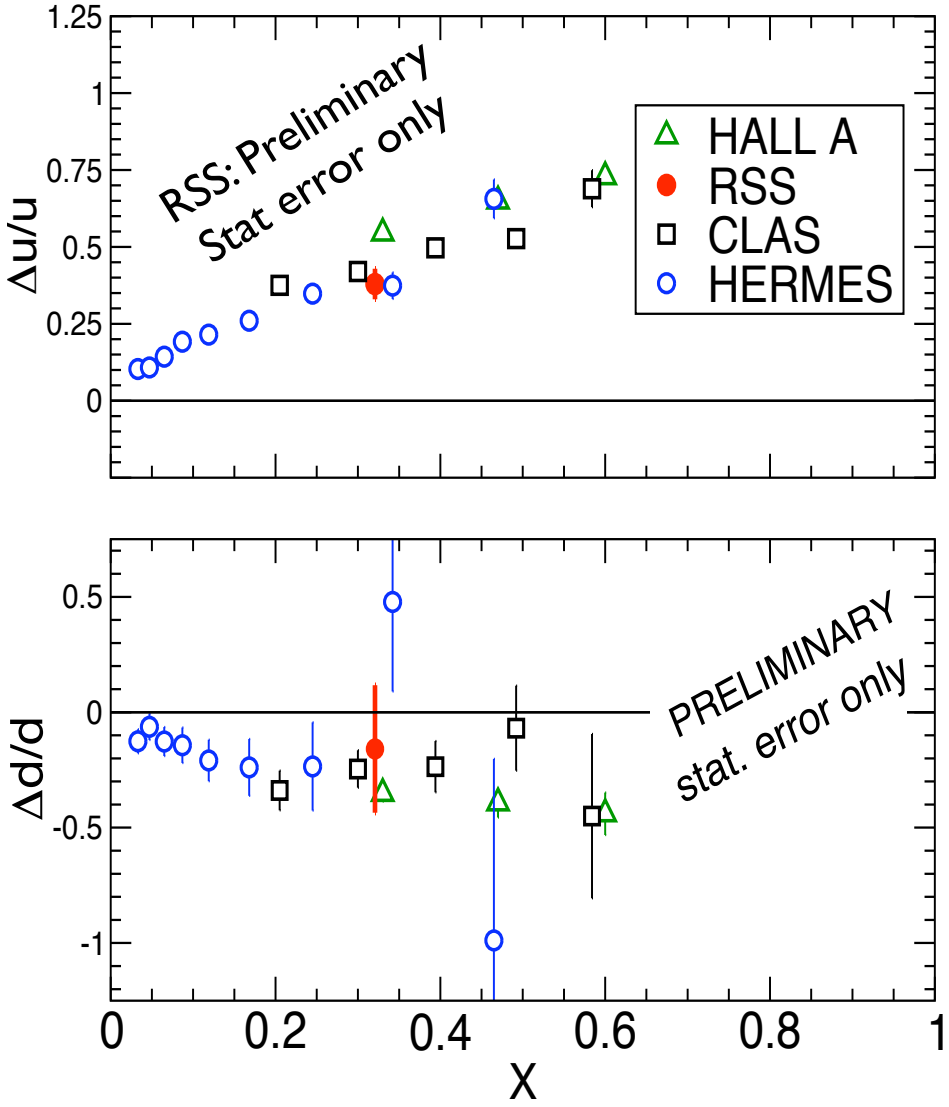
$$\gamma^2 = \frac{Q^2}{\nu^2} = \frac{4m^2x^2}{Q^2}$$

The Burkhardt-Cottingham Sum Rule from RSS proton data



$$\Gamma_2 = \int_0^1 g_2(x)dx$$

Quark Polarizations Δu/u and Δd/d



- Phys. Lett. **B641**, 11 (2006) (K.V. Dharmawardane *et al.*) [CLAS]

$$\frac{\Delta u}{u} \approx \frac{5g_1^p - 2g_1^d/(1-1.5w_D)}{5F_1^p - 2F_1^d};$$

$$\frac{\Delta d}{d} \approx \frac{8g_1^d/(1-1.5w_D) - 5g_1^p}{8F_1^d - 5F_1^p}.$$

- CLAS, RSS: used data for W>1.77 GeV and $Q^2 \geq 1$ GeV^2
- RSS data agrees with world data

Summary

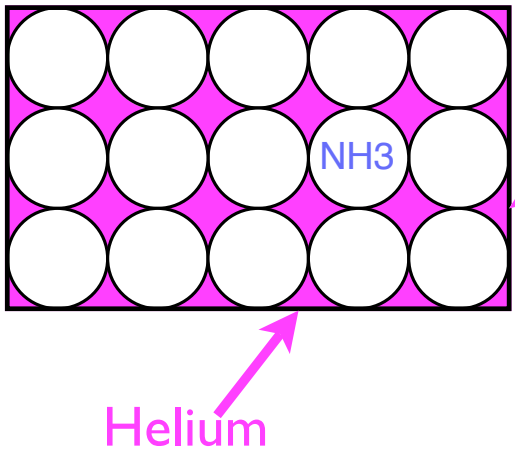
- Precise measurement of the proton and deuteron spin asymmetries A_1, A_2 and spin structure functions g_1, g_2 in the resonance region.
- Studied polarized duality in the resonance region, twist-3 effect, and extracted d_2 matrix element
- Deuteron, neutron and sum rule results are preliminary.
- Proton elastic paper has been published:
  M.K. Jones *et al*, PRC 74, 035201 (2006)
- Proton SSFs paper has been submitted to PRL
  F.R. Wesselmann *et al*. Preprint: nucl-ex/0608003
- New papers on proton and neutron sum rules (K.Slifer) and Deuteron/Neutron SSFs (S. Tajima) will be written.

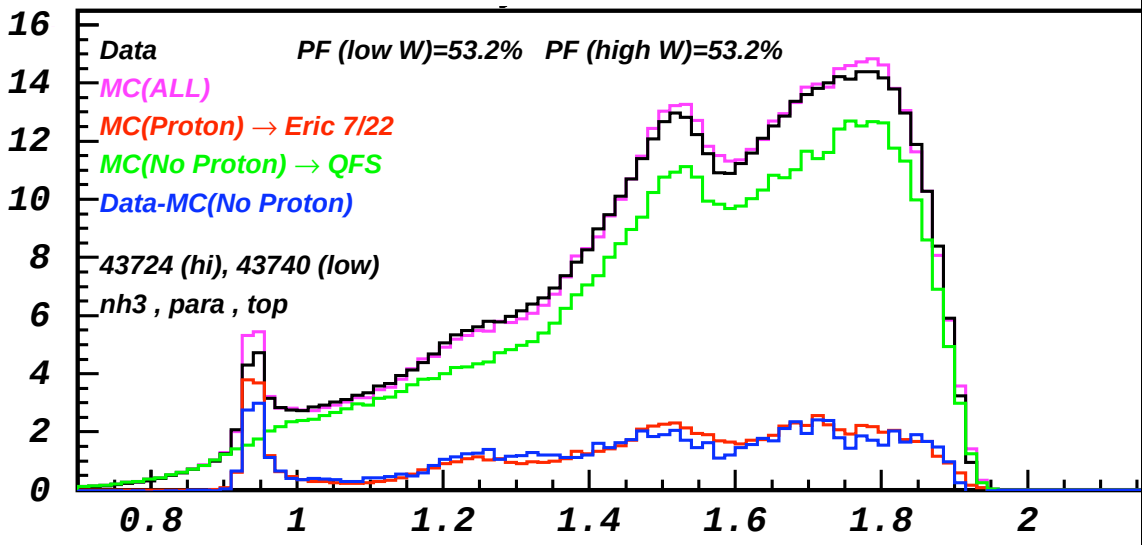
Packing Fraction

Packing Fraction (PF) for the proton target is the ratio of NH_3 to (NH_3 +He).

Similarly for the deuteron target (ND_3)

- PF for each target cell was determined by comparing the simulated W spectrum with data.
- Measured NH_3 PFs: 53-60%, Measured ND_3 PFs: 52-58%, Systematic error in PFs: <2%





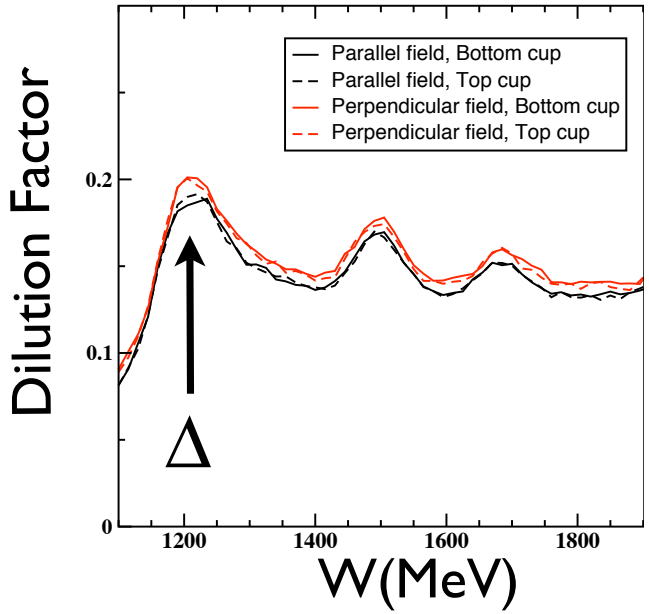
Dilution Factor

Proton

- Dilution Factor: f(W)

f(W)= Rate(proton) / Rate(total)

- Hall C fits for F_2 and R by M.E. Christy); QFS for A>2
- f(w) ~ 0.1-0.2 (resonance region)

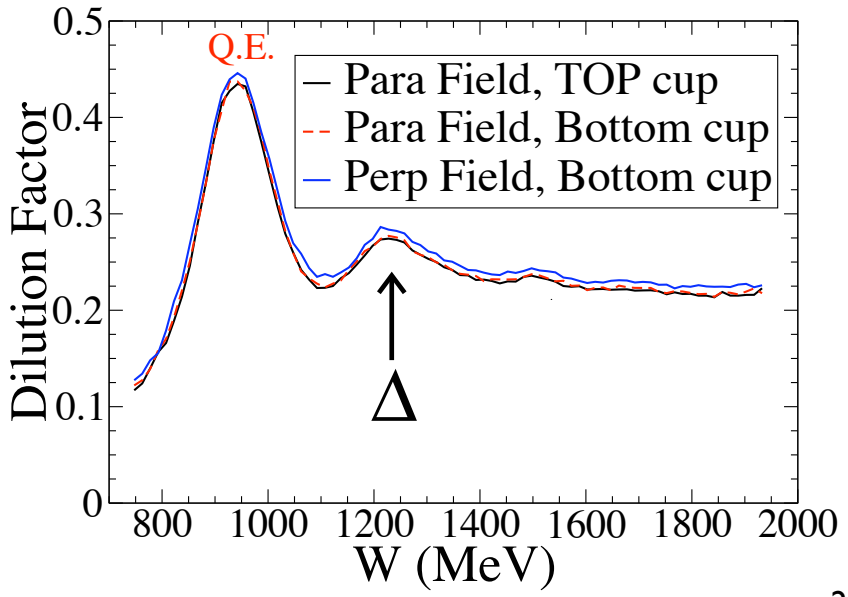


Deuteron

- Dilution Factor: f(W)

f(W)= Rate(deuteron) / Rate(total)

- Fit to the deuteron cross section obtained by I. Niculescu;
- QFS for A>2
- f(w) ~ 0.2-0.3 (resonance region)



Beam-Target asymmetries

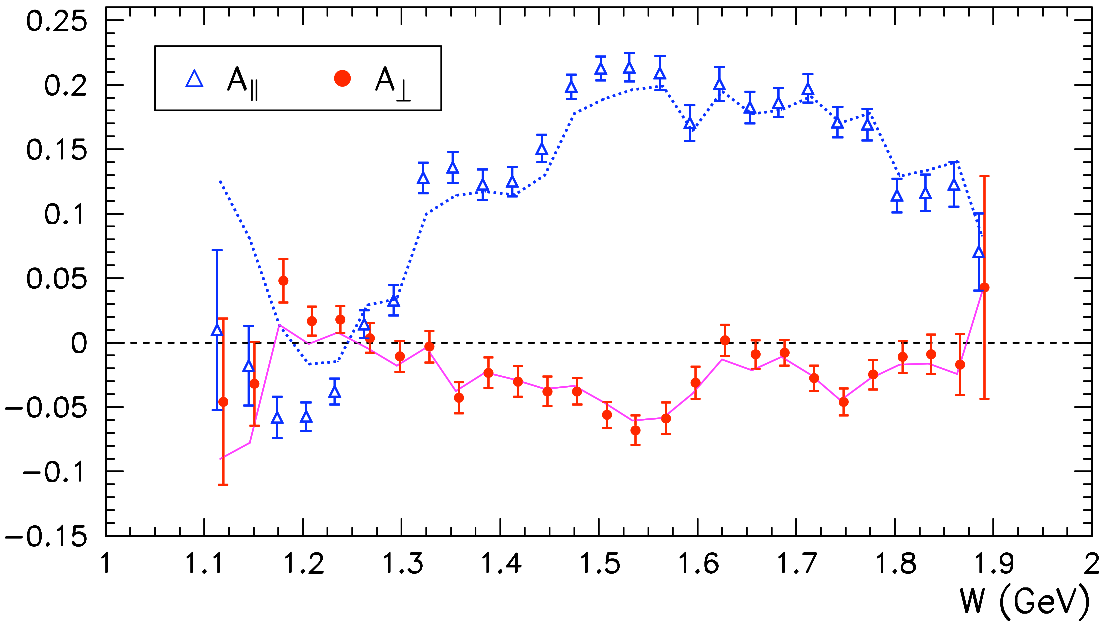
$$A_{raw} = \frac{N^{\downarrow\Uparrow} - N^{\uparrow\Uparrow}}{N^{\downarrow\Uparrow} + N^{\uparrow\Uparrow}} \quad \text{or} \quad \frac{N^{\downarrow\Rightarrow} - N^{\uparrow\Rightarrow}}{N^{\downarrow\Rightarrow} + N^{\uparrow\Rightarrow}}$$

Target polarization: (longitudinal) (perpendicular)

$$A_{\parallel,\perp} = \frac{1}{C_N f_{rc}} \cdot \frac{A_{raw}}{f P_B P_T} + A_{rc}$$

- Counts are normalized by the charge and deadtime
- f = dilution factor; P_B, P_T = beam and target polarizations
- C_N = corrections for ^{15}N asymmetry
- f_{rc} , A_{rc} = radiative corrections.
  POLRAD (Akusevich et al.) modified to include a fit to our data.

Proton $A_\parallel$ and $A_\perp$ versus W



- Points: Fully-corrected asymmetries
  Curves: Without radiative corrections

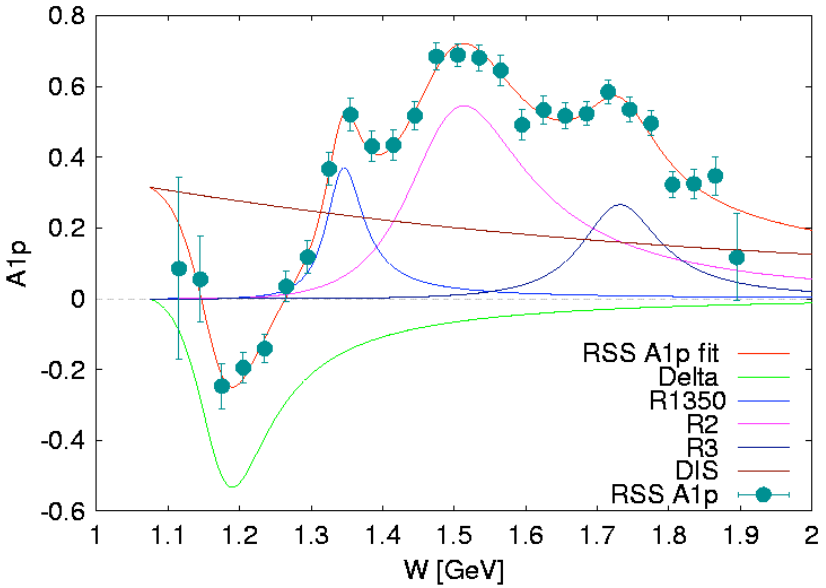
How to get Spin Asymmetries A_1 and A_2

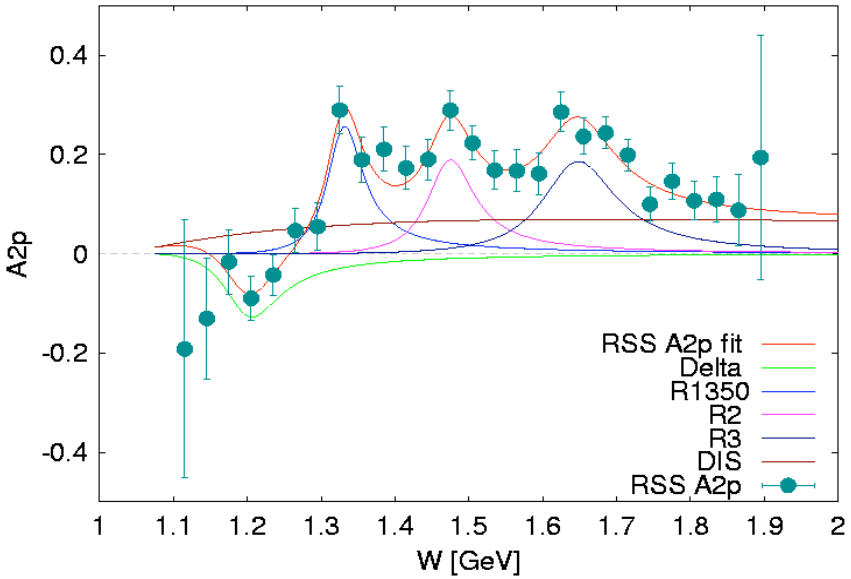
$$A_1 = \frac{1}{(E+E')D'}\left((E-E'\cos\theta)A_{||} - \frac{E'\sin\theta}{\cos\phi}A_{\perp}\right)$$

$$A_2 = \frac{\sqrt{Q^2}}{2ED'}\left(A_{||} + \frac{E-E'\cos\theta}{E'\sin\theta\cos\phi}A_{\perp}\right)$$

- D'(E, E', θ,R) are functions of kinematic variables and $R = \sigma_L/\sigma_T$
- A_1 and A_2 are extracted from the measured $A_{||}$, $A_{\perp}$ and the fit of R (obtained from JLab data) by M.E. Christy
- Determination of A_1 and A_2 in a model independent way (RSS is the only experiment which measured both $A_{||}$ and $A_{\perp}$ on protons and deuterons in the resonance region)

Fit to the Proton SA's





- Four Breit-Wigner resonance shapes plus DIS background
- Fit A_1 and A_2 independently
- Reduced $\chi^2 \sim 1.3$ - 1.5 for 12 d.o.f.

How to get spin structure functions g_1 and g_2

$$g_1 = \frac{F_1}{1+\gamma^2}(A_1 + \gamma A_2)$$

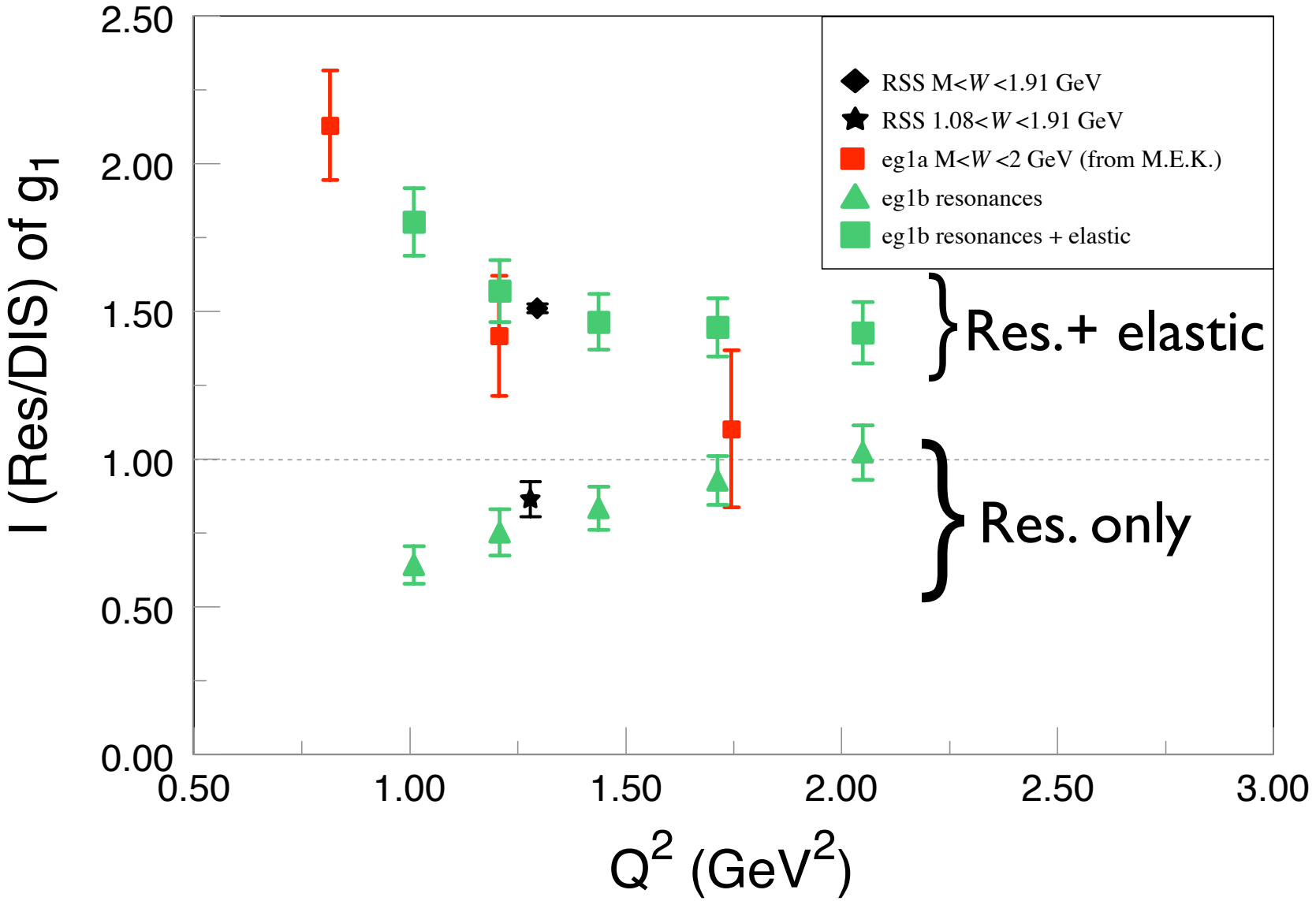
$$g_2 = \frac{F_1}{1+\gamma^2}(A_2/\gamma - A_1)$$

$$F_1 = F_2(1+\gamma^2)/2x/(1+R)$$

$$\gamma = \sqrt{\frac{Q^2}{\nu^2}}$$

- g_1 and g_2 are extracted from the measured A_1 and A_2 using the JLab F_2 and R fits by M.E. Christy (to be published)

Q^2 Dependence of Global Duality

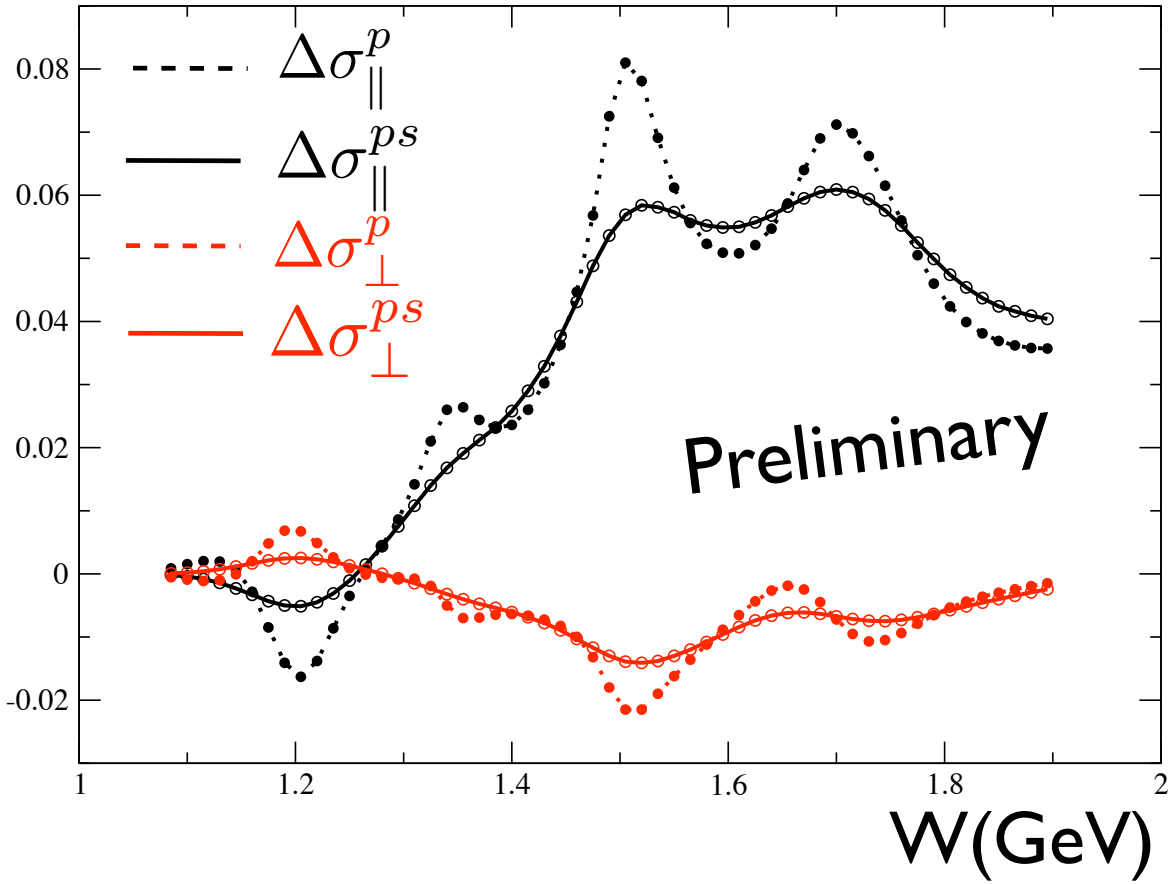


Systematic Uncertainties

	Proton $A_{\|\|}$	Proton $A_{\perp}$
Target Polarization	} **1.1%**	**2.9 %**
Beam Polarization		**1.3 %**
Dilution Factor	**4.9 %**	**4.9 %**
Radiative Corrections	**2.7 %**	**12.9 %**
Kinematic Reconstruction	**0.4 %**	**0.4%**
Total	**5.7%**	**14.2%**

Effect of Smearing (I)

- Proton data fit and Paris W.F. for the deuteron were used to smear the proton cross sections.



Effect of Smearing (II)

- g_{1p} and g_{2p} before and after smearing